

Section 8

Hardware

Hardware

INTRODUCTION

The full complement of EDOMP investigations called for a broad spectrum of flight hardware ranging from commercial items, modified for spaceflight, to custom designed hardware made to meet the unique requirements of testing in the space environment. In addition, baseline data collection before and after spaceflight required numerous items of ground-based hardware.

Two basic categories of ground-based hardware were used in EDOMP testing before and after flight: (1) hardware used for medical baseline testing and analysis, and (2) flight-like hardware used both for astronaut training and medical testing. Individual hardware items are listed in Table 8-1. To ensure post-landing data collection, hardware was required at both the Kennedy Space Center (KSC) and the Dryden Flight Research Center (DFRC) landing sites. Items that were very large or sensitive to the rigors of shipping were housed permanently at the landing site test facilities. Therefore, multiple sets of hardware were required to adequately support the prime and backup landing sites plus the Johnson Space Center (JSC) laboratories.

Development of flight hardware was a major element of the EDOMP. The challenges included obtaining or developing equipment that met the following criteria: (1) compact (small size and light weight), (2) battery-operated or requiring minimal spacecraft power, (3) sturdy enough to survive the rigors of spaceflight, (4) quiet enough to pass acoustics limitations, (5) shielded and filtered adequately to assure electromagnetic compatibility with spacecraft systems, (6) user-friendly in a microgravity environment, and (7) accurate and efficient operation to meet medical investigative requirements.

Even more challenging was the short timeframe afforded hardware development projects, the compressed flight integration schedules, and the rapid turn-around time between flights during which hardware modifications were frequently made. All of these were necessary in order to meet the dynamic requirements of the EDOMP. Given the critical need for quick answers to the many physiological concerns associated with longer duration Shuttle missions, hardware development schedules were highly compressed. Frequently, investigations were manifested for flight prior to completion of the hardware and/or well after standard Shuttle Program manifesting deadlines. Quite often lessons learned through flight experience that could improve data

Table 8-1. Ground-Based EDOMP hardware.

LIDO Isokinetic Dynamometer
Mass Spectrometer
Quinton Treadmill
Q-plex Metabolic Analyzer
Safe Stress System
Cycle Ergometer
Underwater Weighing System
Bioelectric Response System
Data Acquisition/Analysis Systems
EMG System
Visual-Vestibular Data System
Dual Axis Laser Tracking System
Equitest Posture Platform System
Video-Based Motion Analysis System
Doppler/Ultrasound System
Finapres Blood Pressure Monitor
Automated Blood Pressure Monitor
Holter Recorders and Analysis System
Barocuff System
Lower Body Negative Pressure Device
Lifepak Monitor
Strip Chart Recorder
Peripheral Venous Pressure Monitor
Downlink Data Acquisition System
12-Lead ECG
CO Rebreathing System
Video Recorders

acquisition and quality were incorporated in time for the next flight.

Despite these scheduling pressures, flight hardware items were fully certified for safety and compatibility with the Orbiter. While the processing of many items benefited from streamlined reliability testing, hardware considered safety-critical underwent the full scope of reliability tests. The success of EDOMP in pursuing such an aggressive hardware strategy was made possible not only by the dedication of project personnel, but by the cooperation and contributions of the entire JSC flight processing community. In the Extended Duration Orbiter Medical Project, JSC truly achieved a “faster, better, cheaper” flight program.

SPECIFIC FLIGHT HARDWARE AND GROUND SUPPORT ITEMS

Ambulatory Cardiovascular Monitoring Assembly

This assembly supported Detailed Supplementary Objectives (DSOs) 602 and 603. It consisted of a commercial off-the-shelf (COTS) automatic blood pressure monitor (ABPM) (Accutracker II, manufactured by Suntech) and a COTS 9-channel data recorder (TEAC Model HR40G) (Figure 8-1a). The assembly was designed to record blood pressure and heart rate during reentry, landing, and seat egress. A special plug was fabricated for the Biomedical Instrumentation Port (BIP) in the Launch and Entry Suit (LES). The BIP plug allowed placement of the electrodes and blood pressure cuff underneath the LES, while the remainder of the hardware remained in a pocket outside the pressure garment. The BIP plug contained the necessary electrical and pneumatic pass-through connections for the ABPM, and yet provided a hermetic seal of the BIP. Beginning with STS-59 in 1994, four skin temperature sensors (HOBO-TEMP, manufactured by Onset, Inc.) were added to this complement for DSO 603, to document the thermal environment inside the LES (Figure 8-1b).

Modifications to the commercial ABPM were minor and included the development of a custom software routine and changes to the Blood Pressure Cuff and ECG cable, allowing connection through the BIP plug. Additional shielding was also provided to reduce the electromagnetic signature of the device. The TEAC Data Recorder was modified to replace the manufacturer's input connector with dual LEMO connectors, allowing inputs from both the ABPM and a 3-axis accelerometer system, while reducing dimensions of the overall assembly. In addition to the hardware modifications, a custom Nomex softgoods kit was developed to contain the hardware within the LES pocket and to organize the cables in such a way that they would not interfere with crew activities or make donning the hardware difficult during flight. A major emphasis was placed on making the assembly as small and unobtrusive as possible to minimize interference in the event that the crew was required to make an emergency egress from the Orbiter.

Lower Body Negative Pressure (LBNP) System

The LBNP system supported DSOs 478 and 623. It was used to track orthostatic deconditioning in flight by using staged application of negative differential pressures of up to -50 millimeters of mercury (mmHg), and to counteract orthostatic intolerance by stimulating physiological responses that encouraged a redistribution of body fluids. LBNP was used in flight as early as 1973 when astronauts on Skylab 2 underwent experimental protocols in the first



Figure 8-1a. Ambulatory Cardiovascular Monitoring Assembly.

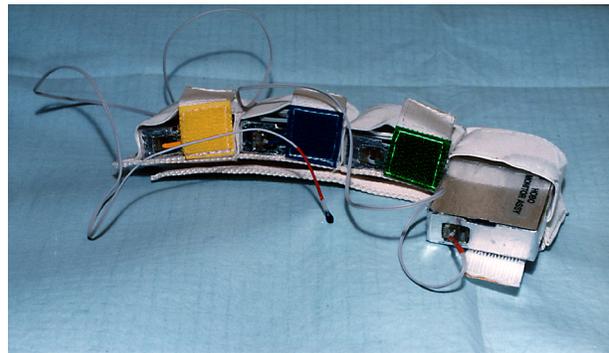


Figure 8-1b. HOBO Temperature Monitoring Device.

generation LBNP chamber [1]. This device, although effective and still in use for ground-based studies, was much too large and heavy to be practical for use on the Shuttle. A second generation LBNP device had been developed for the Spacelab, but was too bulky for stowage and use in the Shuttle middeck. The challenge was to develop a collapsible device, capable of being easily assembled and yet stowed in a single middeck locker. The challenge was met, and the first version of this collapsible system flew on STS-32 in January, 1990. Although hardware operation was successful, the astronauts using the device experienced significant discomfort. During the LBNP protocol the astronaut's body was supported by a bicycle-style seat suspended from the chamber opening. The atmospheric pressure outside the chamber pushed the crew member against the seat, analogous to hanging from a bicycle seat without being able to touch the floor. Crew suggestions following this flight led to an anthropometric redesign of the chamber and the seat.

The main component of the LBNP system was the LBNP Device (Figure 8-2a), which formed a chamber in which the subject was exposed to the varying levels of negative pressure. The LBNP Device consisted of inner and outer cylindrical Nomex bags with an airtight urethane coated nylon bag sandwiched between the two. Woven into the inner Nomex bag was a skeletal support structure of four struts and seven rings fabricated of 304 stainless steel. The struts could be disengaged and folded, allowing the chamber to collapse into a compact cylinder stowable in a Shuttle middeck locker. As mentioned earlier, during the first flight of the LBNP, crew members commented that the device was not comfortable. In an attempt to eliminate discomfort, the LBNP Device was modified. The addition of a ring canted at a 30-degree angle to the open end of the cylinder, and the replacement of the bicycle seat with a flat, tractor-like seat pan allowed the subject to assume a more natural neutral body position within the LBNP Device, and distributed the forces previously centered on the groin across the subject's buttocks. In addition to the seat pan, other modifications to the LBNP Device included: (1) a back rest, to provide support and cushioning to the lower back, (2) a foot rest, allowing the subject a leverage point, and (3) the addition of an iris assembly, which reduced the cross-sectional area at the top of the bag exposed to standard cabin pressure, thereby reducing the suction forces translated to the subject and to the neoprene waist seal.

Maintaining proper waist seal integrity and eliminating leakage was critical to the success of LBNP. Original versions of the waist seal, although basically successful, presented difficulties when subjects of widely varying waist sizes were required to use the same device. This led to the development of removable neoprene waist seals that zipped onto the LBNP Device and could be fabricated to fit different subjects.

Operation of the system was managed by the LBNP Controller (Figure 8-2b). The Controller was a self-contained, programmable integrated logic circuit (ILC) control unit that provided automated pressure control, as well as signal conditioning for ECG, blood pressure, and LBNP Device pressure waveforms. The Controller connected directly to the LBNP Device via a quick-disconnect mounted on the front of the LBNP Device. In order to create a vacuum, a stainless steel flex hose attached to quick-disconnects (QD) mounted on the LBNP Controller and on an Orbiter vacuum source. For middeck operation, the vacuum source was the Waste Collection System (WCS), accessed via a QD mounted on a panel below the Orbiter toilet. For Spacelab operation, the LBNP used the Spacelab Vacuum Vent, accessed through a custom panel fabricated by Marshall Space Flight Center (MSFC). Regulation of the internal vacuum was provided by two solenoid valves, as illustrated in Figure 8-2c. These valves were: (1) a normally open valve on the Controller's vent port, and (2) a normally closed

valve located on the vacuum inlet port. To decrease pressure in the LBNP Device, the normally open vent solenoid was energized, forcing the vent valve closed, and shutting off the LBNP chamber from the cabin. This provided a sealed environment in which to pull a vacuum. At the same time, the normally closed vacuum valve was commanded to the open position to begin evacuation of the LBNP Device. A pressure transducer, located inside the LBNP Controller, was connected directly to the LBNP Device via a dedicated sample port. The pressure transducer sent signals to the Controller's microprocessor, which compared the actual pressure in the LBNP Device to the expected (programmed) pressure. This, in conjunction with the microprocessor's internal clock, allowed the Controller to regulate and control the pressure in the LBNP Device throughout the entire protocol. If power was terminated to the Controller unit, the solenoid valves would automatically default to the vent positions, allowing the LBNP Device chamber to return to ambient cabin pressure.

For simplicity, the Controller was limited to three protocols stored in memory. However, the capability existed to modify the Controller's software and external controls to allow much greater flexibility in executing alternate protocols. The three available protocols used during EDOMP were called "Ramp," "Soak," and "Alternate." The Ramp protocol tested the cardiovascular status of a crew member. The Soak was the treatment protocol and was to be performed within 24 hours of landing to obtain maximal benefits. The Alternate was a modified soak protocol that could be used for contingencies when the LBNP session was interrupted. LBNP sessions were initiated by pushing the appropriate button on the Controller. The Controller then executed the protocol, evacuating the chamber by -10 mmHg increments every 5 minutes until -50 mmHg was reached. The Ramp test ended after 5 minutes at -50 mmHg. During the Soak treatment protocol, the Controller performed a Ramp test before repressurizing the bag to -30 mmHg, where the subject "soaked" for approximately 4 hours. A final ramp to -50 mmHg was performed at the end of the soak to test its efficacy. In the Alternate protocol, the Controller decompressed the LBNP Device to -30 mmHg without performing a ramp test, and held it there for approximately 4 hours before returning to ambient (again without a ramp). A "Pause" feature was also provided. When the Pause button was depressed, the Controller would interrupt the protocol in progress, hold the last target pressure, and display a clock to indicate the time since the pause was initiated.

During all LBNP protocols, blood pressure, electrocardiogram (ECG), and heart rate were monitored with the use of an ABPM, identical to the ones used in the Ambulatory Cardiovascular Monitoring Assembly. The ABPM was connected to the LBNP Controller via a data cable, and analog data from the ABPM were processed by signal conditioning circuitry in the Controller. Analog data,

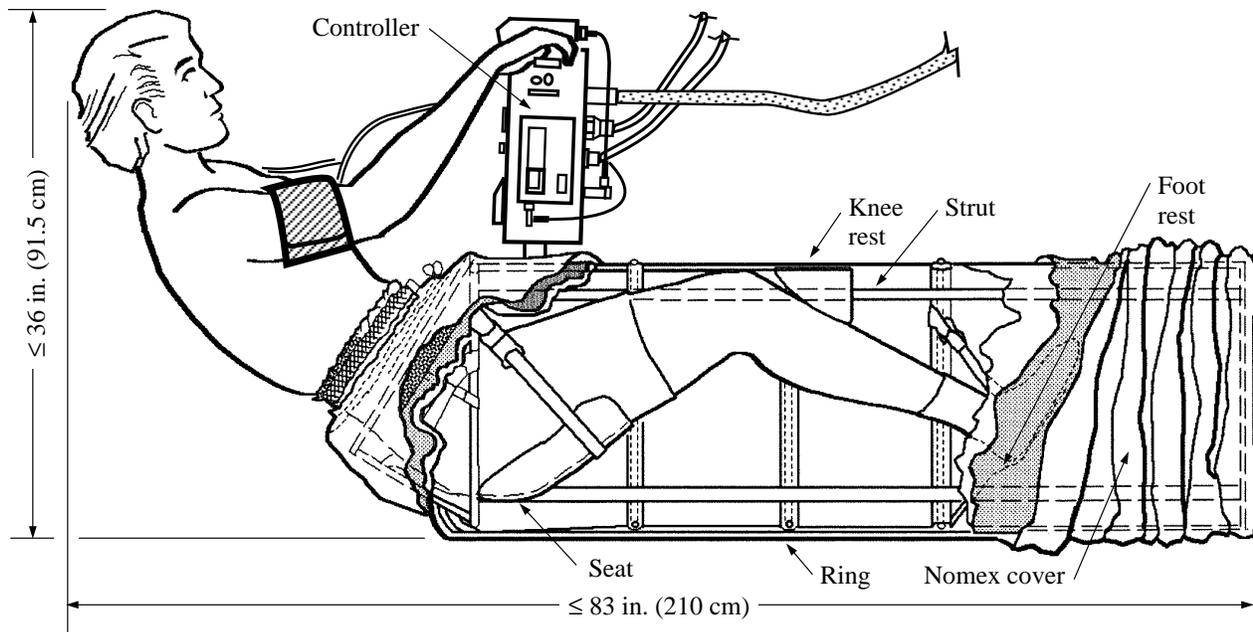


Figure 8-2a. Lower Body Negative Pressure (LBNP) Device.



Figure 8-2b. LBNP Controller.

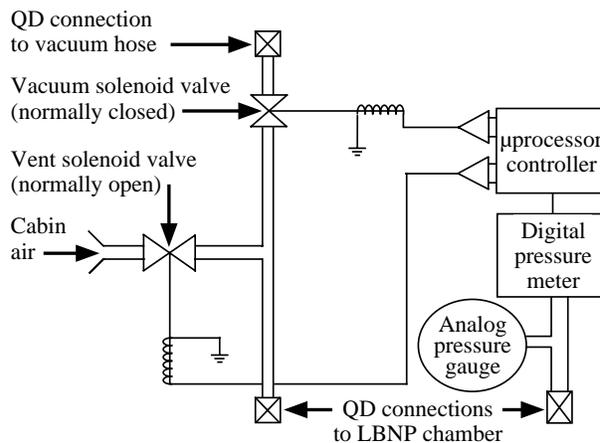


Figure 8-2c. LBNP Controller Schematic.

including continuous ECG, Korotkoff sounds, cuff pressure, LBNP vacuum pressure, and voiced comments were recorded onboard for postflight analysis using a 9-channel TEAC data recorder connected to the LBNP Controller.

For safety reasons, ground-based subject monitoring via telemetry was required during portions of the LBNP test and treatment protocols. Because LBNP was performed both in the middeck and in the Spacelab, the LBNP Controller had to be designed for two operational telemetry interfaces. In the middeck, data were down-linked via the Orbiter Bioinstrumentation System (OBS). In this configuration, conditioned analog data were sent

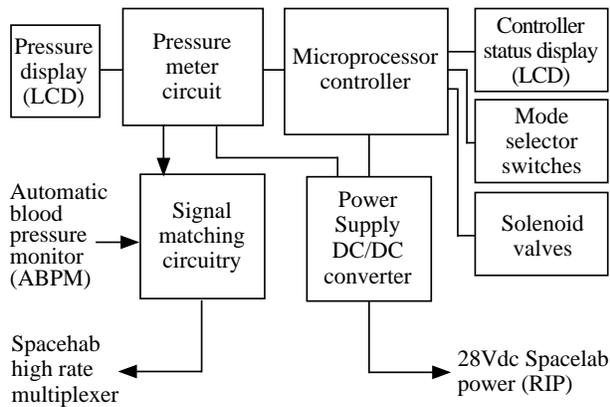


Figure 8-2d. Controller Data Flow Diagram.

via a data cable directly from the LBNP Controller to the OBS, which then digitized and downlinked the data as a part of the S-band communications. The two available OBS channels could be used to downlink any two of three available waveforms: ECG, blood pressure (K-sounds superimposed on cuff pressure), and LBNP pressure.

For Spacelab (Figure 8-2d), the analog signals were sent, via a data cable, to the Data Acquisition System (DAS) described in the next section, which processed data for the Spacelab telemetry system.

Onboard the Shuttle, the LBNP Controller provided real-time feedback to the crew members through a 20-character, 2-line liquid crystal display (LCD) that supplied continuous updates on chamber pressure and displayed a countdown to the next pressure change. An aneroid pressure gauge mounted on the LBNP Controller provided a redundant means of monitoring pressure in the LBNP Device. The ABPM tracked subject heart rate and blood pressure and provided the subject and operator with a digital readout of critical test termination criteria, such as a sudden drop in blood pressure. ABPM heart rate and blood pressure data were recorded on a hard-copy logbook by an astronaut trained to monitor subjects during testing. As a matter of course, a manual sphygmomanometer was also provided for use in the event of failure of or questionable data from the ABPM.

Data Acquisition System (DAS)

The DAS was a custom-designed flight data system for use during biomedical experiments such as LBNP that required access to the Spacelab telemetry stream. The DAS converted the analog signals from the LBNP Controller into digital data, and put the information into a serial data format compatible with the Spacelab High Rate Multiplexer (HRM). The DAS employed parallel processing technology, and consisted of analog signal processing circuitry, a network of analog to digital

converters, an Intel 486-based single-board computer, and a custom designed interface board with an imbedded processor and special output drivers that sent the digital data to the Spacelab HRM. The entire system fit into a compact enclosure measuring $13 \times 7.5 \times 5.5$ inches. The DAS also conditioned the analog signals and routed them to a redundant low rate data system called the Remote Acquisition Unit (RAU). The RAU provided a user time clock signal to the DAS for data synchronization. Both high and low rate data streams were multiplexed into the Orbiter's telemetry system for downlink via the S-band (low rate) and Ku-band (high rate) transmitters, and routed to flight surgeons and scientists monitoring the test on the ground.

Operations Acquisition System In-situ (OASIS)

To maximize benefits from the data sent to the ground by the LBNP Controller and DAS, a new system was developed for data acquisition from the Shuttle downlink telemetry. The OASIS was a portable, ground-based data processing system used to decode, display, and store information received from the Space Shuttle telemetry stream during LBNP operations in the middeck or the Spacelab. The OASIS could be used anywhere that access to telemetry data was available, such as the Science Monitoring Area (SMA) at JSC, the Payload Operations Control Centers (POCC) at MSFC and JSC, or during preflight testing in the Operations and Checkout Building at KSC. The OASIS made use of a custom designed Dual Serial Receiver board, together with special data acquisition cards in a personal computer (PC) system running customized software (developed under a LabViews platform). The OASIS system used two PCs (laptops with expansion chassis or desktop) to perform all of the functions that had previously required two racks of electronic equipment, a MicroVax computer, and a network of MacIntosh workstations. Virtual instrumentation displays on the PC monitors could be customized to perform data analysis in real or near real time, and display selected information to the investigators and medical personnel monitoring the experiment (blood pressure and heart rate trend analysis, pulse pressure monitoring, power spectral analysis of ECG, etc.). Alarms could be programmed to alert when heart rates or blood pressures approached predetermined test termination criteria. The multi-tasking capabilities of the PC workstations were optimized to display data in multiple windows simultaneously.

American Echocardiograph Research Imaging System (AERIS)

The AERIS (Figure 8-3) was a clinical ultrasound/Doppler medical imaging device (Biosound Genesis II), highly modified and repackaged for spaceflight, and

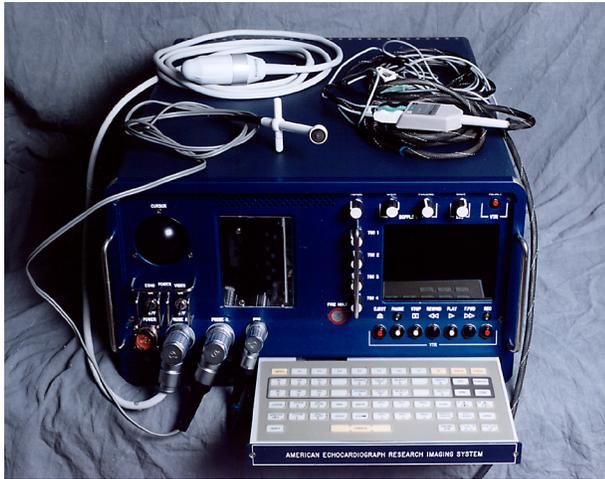


Figure 8-3. American Echocardiograph Research Imaging System (AERIS).

used to record images of the heart during LBNP studies. The AERIS was capable of: (1) displaying one- and two-dimensional images of the heart and other soft tissues, (2) performing noninvasive Doppler blood flow measurements, (3) recording on 8 mm video tape all ultrasound images or route image to an on-board camcorder, and (4) measuring or deriving the cardiac parameters of stroke volume, cardiac output, wall motion, and chamber dimensions.

A number of modifications were performed to make the AERIS useable during spaceflight. An external enclosure and an internal card cage were fabricated that could withstand launch vibration loads and protect internal circuit boards. The device was modified to fit into a single middeck locker. The original power supply was converted from alternating current (AC) to 28 volts direct current (VDC), the standard Orbiter power. The cathode ray tube (CRT) display was replaced with a color LCD flat panel display, and a small 8mm video tape recorder (VTR) was installed to provide recording and playback capabilities. After the first flight of AERIS on STS-50 [United States Microgravity Laboratory-One (USML-1)], a number of improvements were made to enhance cooling efficiency in zero gravity and improve device reliability.

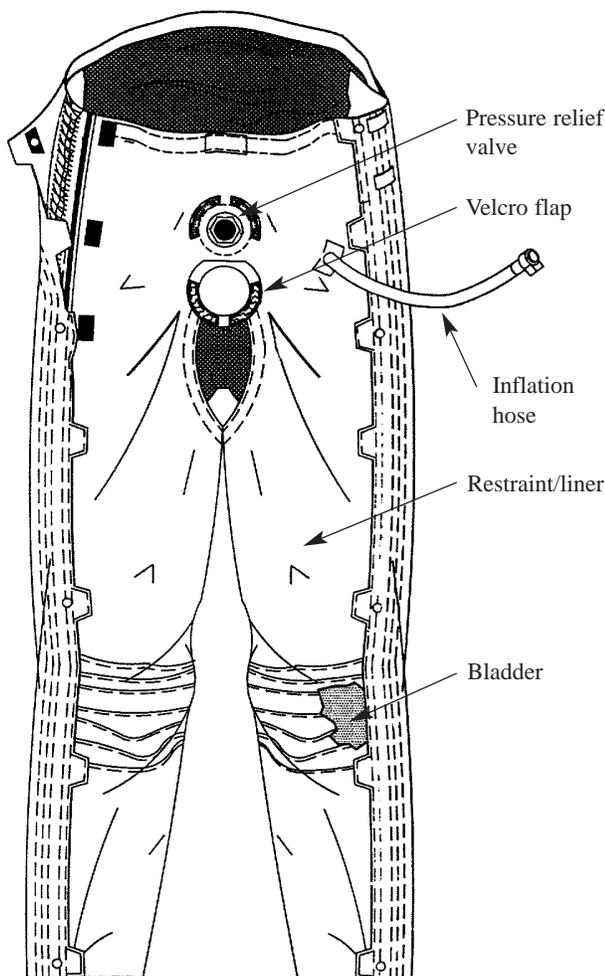


Figure 8-4. Re-entry Anti-gravity Suit (REAGS).

Re-entry Anti-gravity Suit (REAGS)

EDOMP initiated the research and development of a new anti-gravity suit (g-suit) that would improve crew comfort when inflated and provide the physiological protection needed for the Shuttle reentry profile of <2-g (Figure 8-4). Prior to the REAGS, the Shuttle g-suit (model CSU-13) was a five-bladder suit that included abdominal coverage and was designed to provide protection during the high gravity environments.

A 30-month study, conducted with the United States Air Force Armstrong Laboratory, culminated in the fabrication and functional verification of an improved garment that was ready to enter operational status concurrent with the Advanced Crew Escape Suit (ACES). The REAGS garment employed fuller leg coverage than the CSU-13, and deleted the abdominal bladder. It provided greater gravity protection than the CSU-13, at lower pressure, and without the discomfort associated with the abdominal bladder used in the older g-suit. The first Shuttle flight to use the REAGS was STS-71 in July 1995. Later modifications, such as the use of Gortex fabric and a lightweight zipper, were made to reduce the bulky nature of the suit when used in combination with the Liquid Cooling Garment (LCG).

Bar Code Reader

The Bar Code Reader (Figure 8-5) was a modified COTS device (Trakker Scanner by Intermec) used to



Figure 8-5. Bar Code Reader.

simplify repetitive logging of data or samples (food consumed, blood and urine samples, etc.). It was a rechargeable, battery-operated device first used in support of DSO 610. It was used to log each urine sample by scanning the bar code labels on the urine collection devices and the thymol and thimerosal syringes. The laser scanner inside the Bar Code Reader would scan the label when the crew member pushed one of the orange buttons on the side, and the scanned data record along with the current Mission Elapsed Time (MET) would be logged into battery-backed static memory. The Bar Code Reader was also equipped with an alpha-numeric keypad so that information could be entered manually if a label had been damaged or was missing or dirty. The Bar Code Reader was also programmed to scan food items and drinks, and to record exercise sessions. After flight, the Bar Code Reader data were downloaded onto a computer.

Urine Collection Kit

The Urine Collection Kit was designed for the in-flight collection of urine used in metabolic and renal stone studies (DSOs 610 and 612). The kit (Figure 8-6) consisted of a Urine Collection Device (UCD) contained within one 12 × 5 inch ziplock bag, placed into a second 12 × 6 inch ziplock bag. The UCD was a polyvinyl chloride (PVC) bag with an inlet and an outlet port. A syringe was used to draw aliquots of urine through the outlet port for in-flight or postflight analysis. The UCD had a plastic clamp which slipped over the inlet port for added protection against leakage after use. To contain odors and any leaks, the urine kits were placed in a large Nomex bag with a watertight polyurethane-coated nylon lining and a watertight zipper. The zippered opening of this bag had an absorbent filter paper as further protection against any urine leaks.



Figure 8-6. Urine Collection Kit.

In-flight Urine Collection Absorber (IUCA)

The IUCA, used to support DSO 328, consisted of an absorbent filter paper placed into the funnel of the Shuttle Waste Collection System urinal. The filter paper was cone-shaped and would therefore fit different funnels. After the crew member collected urine on an IUCA, it was placed into an ordinary plastic ziplock bag, then into a second ziplock-style bag made of metallized plastic, and finally into a Nomex bag, lined with waterproof polyurethane-coated nylon. The top of this Nomex bag rolled over for closure and tied down with straps. A small rectangular piece of Spandex at the top of this Nomex bag contained some absorbent filter paper to absorb any leaks. The Nomex bag, containing approximately ten IUCAs, was returned to JSC for postflight analysis.

Saliva Collection Kit

Collection of saliva is a noninvasive technique that was used frequently for pharmacologic and metabolic studies. Although several kit configurations were developed to support DSOs 612 and 622, each consisted basically of a Nomex pouch in which a quantity of collection vials was secured by means of foam inserts or elastic straps. Each vial, containing a sterile dental cotton roll, was labeled and color coded, and contained a space for the crew member to record sampling time. The kit also contained a marker, a pair of tweezers (to facilitate removal of the cotton roll from the vial), and inert Parafilm strips that the crew members could chew to stimulate salivation if necessary.

Two different types of collection vials were used. Plastic Salivette vials (developed for NASA by Sarstedt) were used for drug pharmacokinetics studies. After flight, each vial was placed into a plastic adapter that

allowed it to fit into a standard centrifuge test tube holder. The saliva samples were then removed from the vials by centrifugation for subsequent analysis. For studies involving the calculation of total body water, saliva samples were typically collected following ingestion of a tracer such as water labeled with "heavy oxygen" (^{18}O) and deuterium (^2H). In this case, glass lyophilization vials were used in place of the plastic Salivettes because the concentrations of isotopes involved were extremely low, and the plastic vials were porous enough that contamination of the samples via evaporation of the tracer dose and transport through the vial walls was possible. When the glass vials were used, each vial was wrapped in protective Teflon shrink-wrap and adhesive Teflon tape. This reduced the chance of breakage and would have contained the glass fragments if breakage occurred.

Breath Sample Kits

The Breath Sample bags used for DSO 622 were commercial off-the-shelf Mylar bags (QuinTron, Menomonee Falls, WI) with one-way valves. The bags were prepackaged with a reagent that changed color when exposed to gaseous hydrogen. The digestion process was tracked based on the production of gaseous hydrogen. At specific times after ingesting acetaminophen, the subject would collect a breath sample by blowing into the breath sample bag. After flight, the amount of hydrogen at each sample period was determined by the amount of color change resulting from the reaction of the reagent with hydrogen.

Doubly Labeled Water (DLW) Dose Kits

For DSO 612, energy utilization was measured through the use of DLW, which contains the non-radioactive tracers, ^2H and ^{18}O . After ingestion, the tracers were measured in saliva and urine. The DLW Dose Kit contained water with ^2H and ^{18}O . The crew member drank one DLW dose per flight from a standard drink container that had been stored in double ziplock bags to contain any leaks. Kits were stowed in the fresh food lockers and returned postflight for final weighing to see how much water was not ingested.

Performance Test Unit

The Psycho-Log 24 (Data Source, Valflaunes, France) was a self-contained, portable device for measuring a variety of psychomotor functions for DSO 484. It measured approximately $6 \times 4 \times 2$ inches and weighed 11 oz. It could be programmed to administer visual analog scales, a log of sleep and wake times, visual and auditory reaction time tests, a mental arithmetic test, and letter cancellation tests.

Actilume

The Actilume (Ambulatory Monitoring, Inc., Ardmore, NY), used for DSO 484, was a microprocessor-based activity monitoring device ($3 \times 1.5 \times \text{in.}$) worn on the wrist. It contained an accelerometer that measured locomotor activity in three dimensions and a photo sensor to measure illuminance. In addition, external probes such as a skin temperature probe and an external photo sensor could be attached to measure additional variables. A flexible membrane button could be depressed to mark events. The locomotor activity data could be used to estimate sleep variables by using either a pre-programmed or customized scoring algorithm.

Glucometer Kit

The Glucometer Kit, used in support of DSO 612, contained a battery-operated blood glucose meter (ONE TOUCH® II). This was a hand-held device that could measure and display blood sugar levels from a single drop of blood. The kit also included lancets, test strips, control reagents, alcohol wipes, gauze, a Sharps Waste Container, and Band-Aids. The ONE TOUCH II Blood Glucose Meter was commercially available and required only minor modifications for spaceflight.

Drug Administration Kit

The Drug Administration Kit, used for DSOs 612 and 621, consisted of a 12×12 inch ziplock bag that contained one or more Nomex pouches designed to hold drug capsules. Each pouch consisted of two rows of six small Teflon-lined pockets, each with its own Nomex and Velcro closure. Each pocket contained a predetermined dose of the appropriate drug. One pouch, identified with the subject name and color code dot on a label inserted into a Teflon window, was flown for each crew member participating in the investigation.

Heart Rate Watch Assembly

Heart rate data, collected for DSOs 476, 608, and 624 during in-flight exercise, were displayed and stored using this equipment (Figure 8-7). The Heart Rate Watch Monitor (POLAR Vantage XL) Assembly was made up of three parts: the battery-operated wrist monitor, the battery-operated sensor/transmitter, and the chest band. The wrist monitor displayed the time of day, elapsed time, and heart rate, and stored the heart rate data. The chest band was an adjustable elastic belt containing conductive electrodes and transmitter connectors. The sensor/transmitter was activated as it was snapped onto the chest band. The POLAR Vantage XL was commercially available and required only minor modifications for spaceflight.



Figure 8-7. Heart Rate Watch Assembly.



Figure 8-8a. Biotest Microbial Air Sampler (MAS) with Accessories.

Microbial Air Sampler (MAS)

Three types of microbial air samplers (Biotest RCS, Biotest RCS Plus, and Burkard) were tested during the EDOMP for DSO 611. All three were battery-operated, hand-held devices that impacted a measured volume of air onto the surface of an agar medium. The purpose of DSO 611 was twofold: (1) to determine types and levels of bacteria and fungi in spacecraft air and on spacecraft surfaces during the course of long duration missions, and (2) to test the hardware for compatibility with spaceflight requirements. The agar strips and other accessories for the Biotest units were stowed in Nomex pouches attached to a Nomex belt, which could be worn by the crew member for convenience and mobility when sampling (Figure 8-8a). The Burkard unit (Figure 8-8b) required agar dishes rather than strips and was stowed in a Nomex kit which the crew member could easily transport to each sampling site and attach to a wall if desired. The MAS units were commercially available and required minor modifications for spaceflight.



Figure 8-8b. Burkard Microbial Air Sampler (MAS).

Combustion Products Analyzer (CPA)

The CPA (Figure 8-9), used for Development Test Objective (DTO) 645, was a battery-powered, portable, real-time monitoring instrument used for the measurement of four gases that could result from thermodegradation of synthetic materials used in spacecraft. The CPA was developed specially for NASA by Enterra Instrumentation Technologies (Exton, Pennsylvania). The gases to be monitored were carbon monoxide, hydrogen chloride, hydrogen fluoride, and hydrogen cyanide. The CPA contained four electrochemical sensors (one for each gas) and a diaphragm pump to pull air over the sensors. The immobilized electrolyte in each sensor permitted the instrument to function in space and eliminated the



Figure 8-9. Combustion Products Analyzer (CPA).

possibility of electrolyte leaks. The sample inlet system was equipped with a particulate filter that prevented clogging from airborne particulate matter. Other features included a digital readout that displayed gas concentration and various warning signals such as low battery and low flow. The instrument could be set to scan the concentrations of all four gases, or it could monitor one gas continuously. The CPA was flown on the Orbiter for contingency use only. The CPA was to be unstowed and powered on only in the event of a combustion incident. Data obtained by the CPA would provide valuable information to the crew and ground personnel for management of the response to the combustion incident.

Archival Organic Sampler (AOS)

The AOS used for DSO 611 was a passive collection device that was used to detect the presence of volatile organic compounds in spacecraft air (Figure 8-10). Stored in individually sealed aluminum canisters to prevent contamination before and after deployment, each AOS contained a chamber filled with a sorbent medium (typically Tenax) retained by a stainless steel screen. Air passively entered the AOS through a precision-drilled orifice located in the center of a stainless steel plate. The sample rate of an AOS could be varied by exchanging the orifice plate for one with a smaller or larger orifice.

Before flight, each AOS was thermally cleaned, proofed (verified clean) using gas chromatography/mass spectrometry (GC/MS), and sealed inside an individual canister. Up to 12 of the devices could be flown on a mission to support multiple sampling locations and sessions. During flight, a crew member opened and deployed these devices to predetermined sampling locations in the Orbiter. One sampler served as a control and was not opened or deployed. Each AOS was exposed to the cabin atmosphere

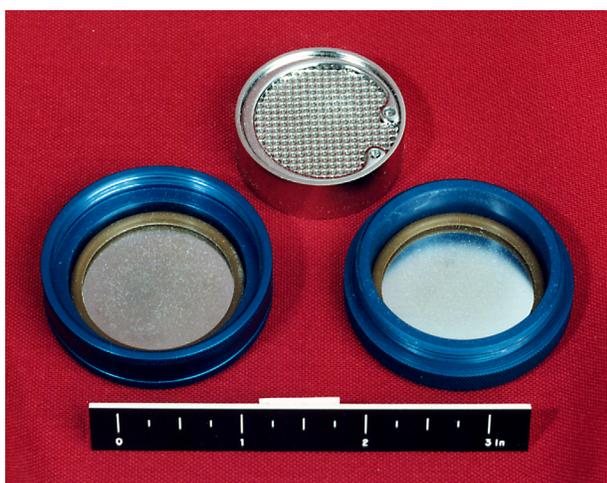


Figure 8-10. Archival Organic Sampler (AOS).



Figure 8-11. Formaldehyde Monitor.

for 24-48 hours. At the end of the sampling period, each AOS was re-sealed inside its canister and stowed for return. Upon return to the JSC Toxicology Laboratory, each AOS was thermally desorbed and analyzed using GC/MS.

Formaldehyde Monitor Kit

The Formaldehyde Monitor Kit, used for DSO 488, consisted of formaldehyde monitor badges (Air Quality Research, Durham, NC) (Figure 8-11), which were passive collection devices modified for use either as personal samplers and worn by crew members near their breathing zones, or deployed on the wall as area samplers. Sampling of the spacecraft atmosphere began when a crew member exposed the badge by removing a seal covering the sampling orifice on its face. Sampling was stopped by placing a second seal over the sampling orifice. The crew member recorded the start and stop time on the badge. Personal sampling was performed during waking hours. Area samplers were deployed for approximately 24 hours at locations that provide adequate movement of air across the face of the sampler. Positive and negative control monitors were also used. The monitors used as positive controls were dosed with known quantities of formaldehyde before delivery for the mission. The negative controls were monitors that were not exposed to the cabin atmosphere during the flight. Exposed monitors and controls were analyzed after flight.

Shuttle Particle Sampler (SPS) and Shuttle Particle Monitor (SPM)

DSO 471 was conducted as part of EDOMP to measure and characterize airborne particulate matter during two Shuttle missions, STS-32 and STS-40. Specifically,

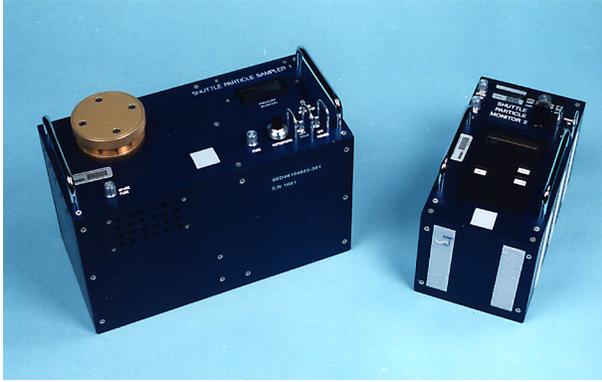


Figure 8-12. Shuttle Particle Sampler (SPS) and Shuttle Particle Monitor (SPM).

the objective was to characterize the concentration, size distribution, composition, and potential sources of airborne particulate matter in the Shuttle flight deck and middeck areas. The instrumentation developed for this experiment consisted of (1) two SPS units which collected particles in four size fractions during two 24-hour sampling periods, and (2) the SPM which continuously monitored and stored particle concentrations during the mission (Figure 8-12). The SPS and SPM hardware were developed jointly by NASA and the Particle Technology Laboratory at the University of Minnesota.

The SPS was $12.5 \times 6 \times 9$ in. in size and weighed 20.7 lbs. The SPS was self-contained and included a particle collector, vacuum pump, filter, control circuitry, and battery pack. Functionally, the SPS sorted and collected particles in four size fractions: $<2.5 \mu\text{m}$, 2.5 to $10 \mu\text{m}$, 10 to $100 \mu\text{m}$, and $>100 \mu\text{m}$. Those particles $>100 \mu\text{m}$ were collected on a 150-mesh screen with $100 \mu\text{m}$ openings, located in the sampler inlet cap. Particles in each of the other three size fractions were collected on 37 mm diameter filters made of Teflon membrane material. Two virtual impactor stages, each consisting of six parallel nozzles, were used to size-fractionate the sampled particles on the basis of their aerodynamic diameter. The samples collected with the SPS underwent a variety of analyses. All filters were weighed before and after sampling to determine the mass concentration of particles collected. Fine particle fractions were then analyzed for elemental composition by x-ray fluorescence. Course particles were analyzed by scanning electron microscopy to determine single particle morphology.

The SPM measured $10.5 \times 5 \times 6.5$ in. and the unit weighed 10 lbs. The SPM consisted of four primary components: a MiniRam photometer, a data logger, and two battery packs. The MIE Model PDM-3 MiniRAM (MIE, Bedford, MA) provided a real time, in-situ measure of the particle concentration based on the nephelometric principle. The minimum, maximum, and average particle

concentration during each 15-minute sampling period was automatically collected and stored in the data logger.

Visual-Vestibular Data System (Superpocket)

The Superpocket System, a physiological signal acquisition system, was used with DSO 604 Operational Investigation-3 (OI-3) to record electro-oculogram (EOG) and head movement data on orbit and during Shuttle entry. The Superpocket System consisted of a target, the data acquisition and control system, cables, batteries, a TEAC data recorder, and the Goggle Assembly. The Goggle Assembly consisted of a laser pointer, a polymer dispersed liquid crystal (PDLC) light occluding lens, EOG electrodes, and rate sensors (Figure 8-13). A remote control device was used to operate the laser and the PDLC lens. A Subject Preparation Kit included electrodes, electrode gel, and accessories. The system was designed to fit into one middeck locker and did not require Orbiter power.

The Superpocket System recorded up to twelve analog channels and one voice channel for subject commentary. The EOG signals were amplified 4000 times with a bandwidth of 0 to 700 Hz. Full scale after amplification was four to five times the effective range of EOG, allowing relatively strong drifts during recording. Each analog channel arriving in the Superpocket electronic box was filtered with an anti-aliasing, fourth order Bessel filter and sampled every 7ms with a resolution of 12 bits. These twelve channels were multiplexed on two pulse-code-modulation channels and recorded on the TEAC data recorder. The subject was instrumented with EOG electrodes above and below the eye. Electronic Light Occluding Goggles (ELOGs), fabricated from off-the-shelf ski goggles, were also worn to either allow vision

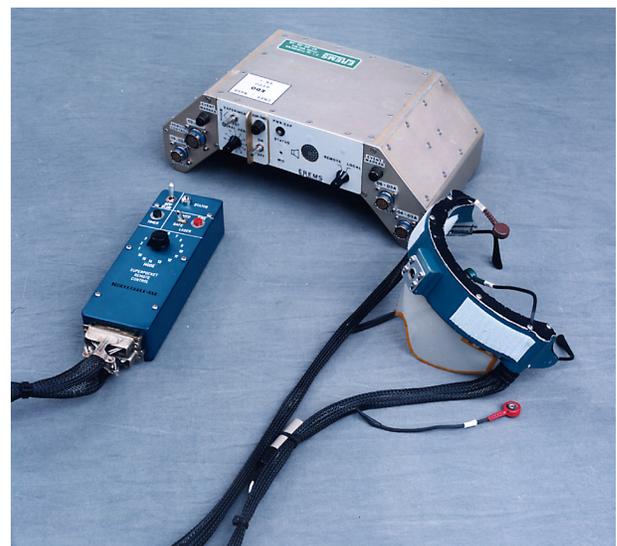


Figure 8-13. Superpocket System.

or occlude vision during testing. The lens was covered with a PDL film which was opaque in its natural form and clear when power was applied. The ELOGs were adjustable to fit any crew member. The goggles were placed over the subject's eyes and the recording session was started by pressing a button on the remote control. The Superpocket System data acquisition and control module was developed by the French Space Agency, Centre Nationale d'Etudes Spatiales (CNES) and modified under the direction of the NASA/JSC Neurophysiology Laboratory. All other components were developed by NASA/JSC.

Locker-Mounted Video Camera System

The Locker-Mounted Video Camera (Figure 8-14) was used to provide DSO 620 investigators with an objective view of crew member balance and equilibrium immediately after landing and wheels stop. The system was designed to fit into one middeck locker and required a special locker door with an opening for the camera. The Locker-Mounted Video Camera System consisted of a commercially available video camera (Sony CCD-TR7), an aluminum camera mount held in position in the locker by dense polyethylene foam, a light attached to the video camera to illuminate the immediate area of the video recording, and accessories, including a headband, marker harness, two batteries, video tape, Velcro visual targets, and a remote control.

For operation, the remote control was attached to the video camera with a quick-disconnect type connector. In preparation for performing the DSO after landing, the crew member performed a quick check of the remote control and camera while on orbit. After wheels stop, the crew member donned the headband and harness, and with the remote control, activated the camera for data recording.

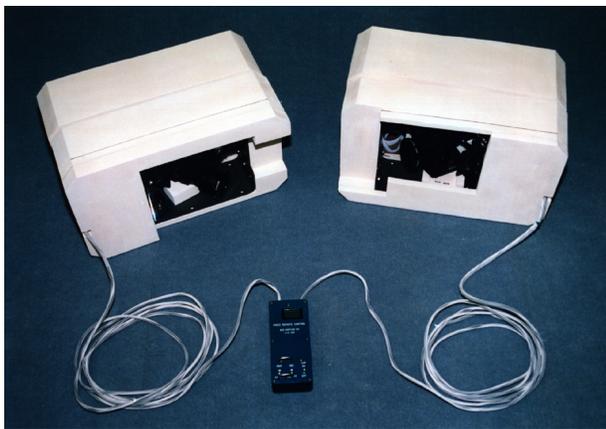


Figure 8-14. Locker-Mounted Video Camera System.

Cycle Ergometer (CE)

The CE, used in conjunction with DTOs 651, 658, 682, DSOs 608, 618, 476, and as an operational exercise device, was developed as part of a suite of exercise equipment to be used for maintaining cardiovascular and musculoskeletal fitness during EDO flights. An additional goal was to evaluate candidate exercise hardware that might eventually be used on the International Space Station. The CE system was conceived to maximize comfort, minimize acoustic noise and vibration, and yet provide reproducible, quantifiable workloads for comparison of exercise profiles in flight and on the ground.

The CE system consisted of the Cycle Ergometer (load module), a mounting frame, and an accessories case containing pedals, cycling shoes, etc. Innovision, A.G. of Odense, Denmark, developed the CE load module under contract to KRUG Life Sciences, Inc.

The workload mechanism in the load module consisted of a conventional flywheel and braking-band system, with the resistance being controlled by a stepper motor that regulated braking-band tension. In the event that power was not available, workload could also be adjusted using a manual knob to increase or decrease tension on the braking band. An external control panel was used to display deviation from the desired pedal cadence (from 50 to 120 rpm in increments of 5 rpm) and to set the desired workload (from 0 to 350 W in 25 watt increments). The CE also had a serial data port, which provided the capability to receive commands and be controlled from an external computer, allowing predefined protocols to be executed automatically. Data such as achieved work load and RPM could be continuously recorded on the computer during execution of the protocols. The CE was designed to operate on 28 VDC power at 15 watts.

A major design challenge was the mounting frame, which had to include structural elements for attachment to the Orbiter during launch, as well as a means of subject restraint. During the development phase, testing on board the KC-135 showed that a recumbent cycling position was extremely comfortable and stable in zero gravity, and required only a seat back to offset the loads generated by the legs while pedaling. The use of handlebars and/or an upright seat was less comfortable and caused arm fatigue as the operator attempted to stabilize him/herself by gripping the handlebars tightly. Thus the recumbent position was chosen for the CE.

For launch, the CE interface frame had to mate to the middeck floor using the same attachment points used by the Shuttle Treadmill (mounting studs of the type used in military cargo aircraft). However, the launch location was not suitable for on-orbit exercise for a variety of reasons. Instead, it was decided that the attachment points used during launch and landing for mission specialist seats (which are normally removed and stowed for on-orbit activities) were ideally placed for exercise using the

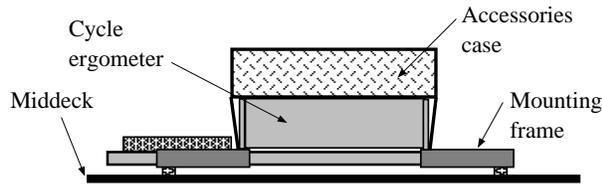


Figure 8-15a. Cycle Ergometer in Launch and Landing Configuration.

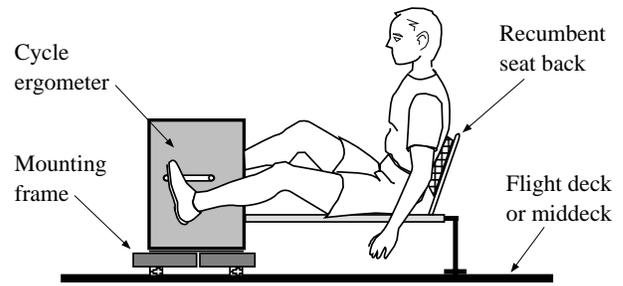


Figure 8-15c. Crew Member Exercising on Cycle Ergometer.

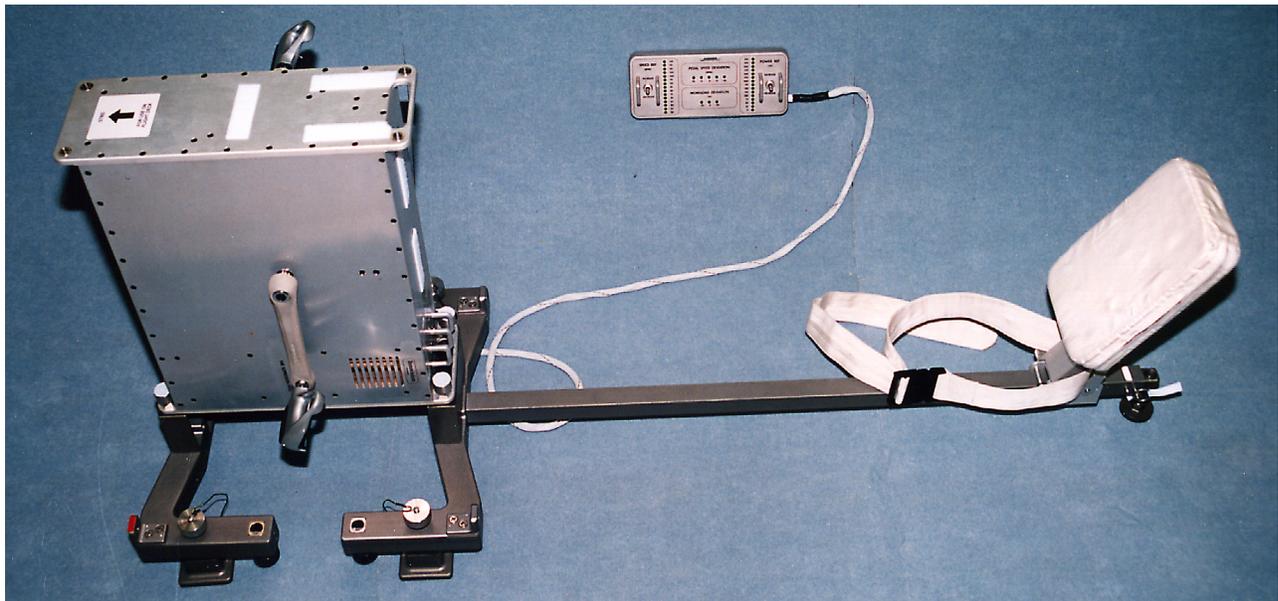


Figure 8-15b. Cycle Ergometer in Deployed Configuration.

CE. This offered the added advantage of allowing the CE to be used either on the flight deck or the middeck. However, since the footprint of attachment points for the treadmill is different from that of the mission specialist seats, a novel approach to design of the CE mounting frame was required. The result was a light weight, two-piece frame that was could be easily reconfigured by crew members in orbit. For the launch configuration, the CE load module lay flat on its side (to lower the center of gravity) on the two halves of the mounting frame. The load module and seat back stem became structural members for launch (Figure 8-15a).

For operation on orbit, the positions of the two mounting frame halves were reversed, and the CE load module was placed upright on top of them. The pedals, control panel, and power cable were connected to the CE. The seat back was positioned on the seat stem, and was set at a comfortable angle and distance from the pedals (Figure 8-15b). The exercising position is shown in Figure 8-15c.

Evaluation of the CE (as DTO 651) occurred on three flights and included hardware setup and operation, as well as determination of physiological responses during CE exercise. The results showed the CE to be an effective exercise device for use during spaceflight.

Ergometer Vibration Isolation System (EVIS)

Vibration on the orbiting Shuttle, which can be caused by many sources, disturbs sensitive microgravity experiments. The need to preserve the microgravity environment and ensure success of these experiments must sometimes be considered when devising means whereby the astronauts can receive adequate in-flight exercise to reduce muscle atrophy, loss of aerobic capacity, and general deconditioning. As mission duration increases, the need for regular exercise becomes even more important. Thus, the need for an effective method to minimize exercise-induced vibration was high priority for the EDOMP.

EVIS, developed to isolate the vibration caused by cycle ergometer exercise, was flown on STS-50 and evaluated by DTO 658. The EVIS employed isolators (composed of linear bearings, springs and dashpots) at four corners of a special one-piece CE mounting frame to inhibit transfer of forces to the spacecraft structure, and four active "throw-mass" type stabilizers to counteract the forces induced by exercise and stabilize the ergometer. The stabilizers used linear motors to drive the throw masses. Accelerometers and sophisticated control feedback circuitry were used to detect the forces and control the motion of the stabilizers. Because of the significant amount of power required by the stabilizer motors, power for EVIS was provided by the Orbiter 120 VAC 400 Hz system, internally rectified to DC within the EVIS electronics (the CE was powered by 28 VDC as described above). Isolation was provided in all three axes; however, through modeling and analysis it was decided that the primary axis of stabilization should be that in which the primary motion of the legs occurred (i.e., parallel to the seat stem in Figure 8-15c). Data were collected by the Space Acceleration Measurement System (SAMS) payload during ergometer runs with and without EVIS. Results indicated that EVIS reduced the vibration significantly. However, the results from this DTO also showed that a passive system, without the active stabilizers, was capable of significantly reducing the level of vibration transmitted to the Orbiter during cycle exercise. In addition, analysis of video collected during tests revealed that the motion most in need of stabilization during ergometry was not translation in the plane of the seat stem, but rather roll about an axis parallel to the seat stem. Given the simplicity and reduced weight, volume, and power requirements of a passive (as compared with active) system, EVIS was not recommended for further development for ergometry. However, the EVIS control system and stabilizers became the basis for a vibration isolation and stabilization system that would later be developed for the International Space Station treadmill.

Passive Cycle Isolation System (PCIS)

PCIS evolved from the lessons learned from EVIS. PCIS hardware (Figure 8-16) worked by allowing the ergometer to free-float using low force isolators connected to the Orbiter.

PCIS consisted of four isolators that were installed between the CE mounting frame and the Orbiter floor. The isolators were of a much simpler construction than the EVIS isolators used previously. Each isolator was composed of wire rope wound into several loops to form a sphere of about 5 inches in diameter. During exercise, the isolators responded independently to the motion of the crew member, allowing the system to rock back and forth. Each isolator experienced the full spectrum of

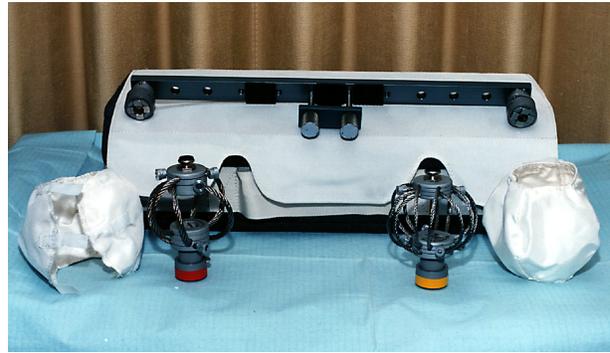


Figure 8-16. *Passive Cycle Isolation System (PCIS).*

disturbances, including torque, translation, compression, and extension forces. The restoring force produced by the isolator was a function of the stiffness of the wire loops comprising the sphere. The wire ropes essentially functioned as both springs and dampers, isolating the motion of the ergometer and acting as energy absorbers by bleeding off a small amount of energy.

PCIS was first flown through DTO 682 on STS-62 in February, 1994. Although the isolators performed as expected to reduce loads transmitted to the spacecraft, it was also seen that additional stabilization was required for effective exercise.

Inertial Vibration Isolation System (IVIS) for the Cycle Ergometer

IVIS was another product of the lessons learned from the EVIS experiment. IVIS was conceived to provide the roll stabilization lacking in EVIS and PCIS. The IVIS consisted of two aluminum boxes that mechanically interfaced with the cycle ergometer (Figure 8-17). Each box contained a throw mass, mounted on linear bearings, and a system of linkages to drive the throw mass. The IVIS boxes were geared directly to the pedal shaft. As the astronaut pedaled the ergometer, the throw masses moved inside the IVIS boxes to create a counter-torque which was applied to the ergometer. This counter-torque acted to nullify the major torque created by the motion of the cyclist's legs and upper body. The torque created when riding the cycle was dependent on cycling speed and workload. Weight and cycling style were major factors in cycling disturbance, so the ability to allow for gross adjustments was added. Therefore, IVIS boxes were equipped with a gain setting selection of low, medium, or high, signifying the amount of counter-torque to be delivered through the system. The masses traveled a maximum of 3.5 inches in the high gain setting to provide an oscillating torque on the ergometer, opposing the exercise-induced torque. When the gain was properly set, the torque produced by the IVIS boxes was equal and opposite to the torque produced by the cyclists.



Figure 8-17. Cycle Ergometer with Inertial Vibration Isolation System (IVIS) Boxes attached.

IVIS was conceived to work in tandem with PCIS. The combined systems were first flown on STS-65, International Microgravity Laboratory-2 (IML-2) in July, 1995 and yielded excellent results. The Space Acceleration Measurement System (SAMS), which was used to record vibration and disturbances during Shuttle missions, and the MMD (see below) confirmed this finding. Video analysis and crew comments also attested to its effectiveness. The PCIS and IVIS combination was also flown in October, 1996 on STS-73, United States Microgravity Laboratory-2 (USML-2), and again yielded excellent protection against microgravity disturbances, as confirmed by the MMD.

Microgravity Measuring Device (MMD)

The MMD, a compact, lightweight acceleration measuring system with the capability to measure, display, and store in-flight acceleration data, was connected to an Orbiter-supplied Payload General Support Computer (PGSC) as the user interface and data storage device. The MMD was ideal for use on missions where real-time acceleration data could enable the crew to make assessments regarding onboard activities and the impact on the microgravity environment. The MMD also provided the capability to send acceleration data files to the ground via telemetry (downlink), thus allowing investigators to observe and evaluate any disturbances to which their payloads were subjected.

Although the MMD was originally developed to support activities for the Wake Shield experiment, one unit was modified for middeck application (Figure 8-18). The primary objective was a performance assessment of PCIS and IVIS with the cycle ergometer. During exercise on the CE with the PCIS and IVIS, crew members observed real-time acceleration data measured on the MMD and displayed on the PGSC. The secondary objective was to evaluate the ease of use of MMD. The MMD was flown as DTO 913 on two microgravity missions: STS-65 (IML-2) and STS-73 (USML-2). The STS-65 crew reported that the MMD was easily set up and stowed and that the software written to drive the data display and acquisition was straightforward and user friendly. The crew members provided some input to assist engineers in fine-tuning the device before it was flown on STS-73. The MMD again performed quite satisfactorily on STS-73. Crew members collected data that were downlinked to the ground, allowing payload investigators to view the acceleration environment on board the Orbiter during exercise and other activities.

EDO Treadmill

Radically different from its predecessor, the Shuttle treadmill, the EDO Treadmill (Figure 8-19) incorporated significant design changes intended to reduce acoustic noise output, increase comfort, and provide the ability to quantify workload. In comparison with the Shuttle treadmill, the EDO Treadmill, tested under DTO 659, had a longer running surface, a more comfortable and stable crew restraint harness, electronically adjustable devices to apply restraint force, and the capability to display effective weight (restraint force) of a subject. A control

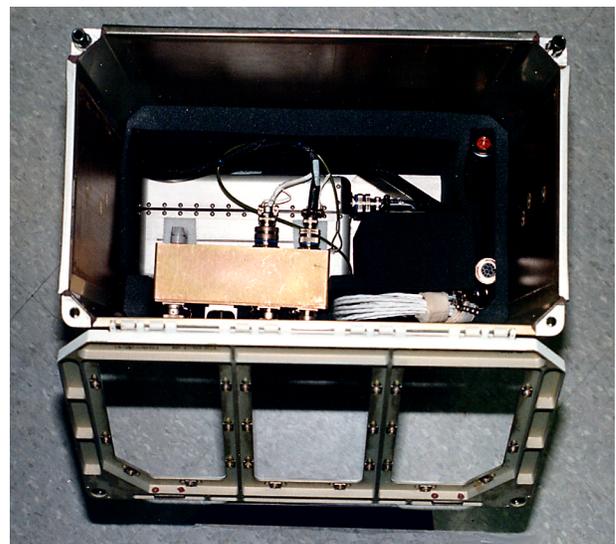


Figure 8-18. Microgravity Measuring Device (MMD) mounted in Middeck Locker.

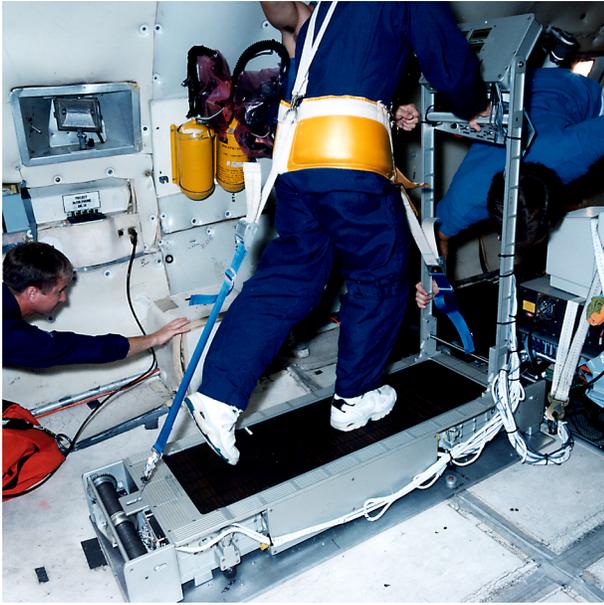


Figure 8-19. Subject Using EDO Treadmill on KC-135.

panel provided a means of adjusting restraint force, and displaying feedback on several exercise parameters such as speed and distance traveled. The EDO Treadmill was a passive (non-motorized) device and could be used with or without Orbiter power, though control panel functions were not available in the unpowered mode.

Major components of the EDO Treadmill included the tread running surface, Subject Load Devices (SLDs), a Device Interface Box (DIB) containing the majority of the electronics, a folding handrail with control panel and integral credit card memory (CCM) data storage system, and an accessory bag containing the subject harness, exercise clothing, shoes, and other accessories.

The running surface was 44 inches long and 13 inches wide, and consisted of a flexible belt to which rigid tread segments were attached, allowing flexion in only one direction. The tread belt was supported by two large diameter rollers at the forward and aft ends of the treadmill, and by two longitudinal support members with a series of small rollers running the length of the running surface. This was a complete change from the older treadmill design, which had incorporated hollow metal segments with wheels at both ends that moved around a “race track” in the side walls of the treadmill. The new design dramatically decreased the noise level of the treadmill during use and provided a more natural “feel” for the subject when running. Load cells installed under the longitudinal support members provided information on the restraint force and on foot strike forces.

One of the most difficult challenges in designing a device for running in microgravity was development of a

comfortable, effective subject restraint system. Because of the absence of gravity, a load must be applied to the subject in order to allow jogging or running. The new treadmill featured two SLDs and a subject-worn harness that attached to the treadmill at three points. The SLDs attached to the forward and aft faces of the treadmill and produced restraint forces using adjustable torsion springs coupled to cable-feed pulleys. The amount of load applied by the SLDs was controlled by the subject, using a keypad on the control panel. When the subject entered the desired restraint force, a microprocessor in the control panel sent commands that were relayed to the SLDs. A motor control circuit in each SLD then increased or decreased the preload on the torsion springs to achieve the desired restraint force. A linear potentiometer in each SLD provided feedback on motor position, which was proportional to the load supplied by the SLDs. Each SLD also contained a load cell to measure actual restraint force applied by the cable. Together, the two SLDs provided a restraint force of up to 220 pounds in the axis normal to the tread surface. The control panel displayed the actual versus desired load, allowing the crew member to adjust to a specific load. Subject load could also be varied by means of adjusting the length of the harness strap connected to the SLD cable.

The control panel displayed speed, distance, heart rate, percentage grade (calculated by differential force between the forward and aft SLDs), elapsed time and restraint force. A scrollable menu function allowed complete subject interaction with treadmill parameters. The display panel was the subject’s interface to the treadmill electronics.

The CCM access slot in the control panel was used to input and output data to and from the treadmill microprocessor. Data such as actual restraint force, average speed, duration of exercise, foot-strike forces, and heart rate could be stored directly on a subject-unique CCM card. In addition to storing data, the card could be programmed preflight with specific exercise profiles. By reading data stored on the card, the SLDs could be automatically commanded to load the subject to a specific weight, and target speeds and times could be displayed on the control panel.

In October, 1994, crew members on STS-64 first ran on the EDO Treadmill in flight. During this 9-day mission, the treadmill was used on the middeck. Crew comments were very favorable, and one crew member ran “around the world” (for one complete 90 minute orbit) on two separate occasions during the mission. In July, 1995, when the Orbiter docked with Russian Space Station Mir during STS-71, Russian and U. S. crew members returning from the Mir also used the treadmill after over 100 days’ exposure to microgravity. During this flight, the treadmill was installed in the Spacelab module.

The EDO Treadmill became the basis for the treadmill being developed for the International Space Station.

EDO Rower (MK-1 and MK-2)

Two rower ergometers, tested through DTOs 653 and 673, were developed to provide Space Shuttle crew members with an exercise alternative to the treadmill and ergometer. The rowers were the final element in the suite of EDO exercise hardware and were designed to be quiet and effective, while requiring minimal stowage space and electrical power. The flexibility of using a rower as an aerobic device (with traditional rowing) as well as its use with accessories for anaerobic resistive exercises, made it a suitable option for many in-flight applications.

The first generation rower, known as the MK-1 device, was flown on STS-42, STS-53, STS-54, and STS-56. It made use of a magnetic eddy current braking mechanism to vary the workload. A solid copper flywheel rotated between the legs of a forked armature with fixed magnets attached to each leg. A simple sliding lever moved the armature to control how much of the surface of the flywheel was covered by the magnets (and thus the resistive force). A chain and sprocket with a free-wheeling clutch coupled the flywheel to the rope spool, and a power spring provided the recoil force. A tiny DC generator coupled to a voltmeter gauge graduated in arbitrary units provided a relative indication of flywheel speed. The combination of workload setting, flywheel speed, and rowing cadence could be used to compare relative workloads preflight and in flight; however, such comparisons were largely subjective unless sophisticated means such as monitoring oxygen consumption ($\dot{V}O_{2max}$) were employed. The inability to precisely quantify workload was a major limitation of the MK-1 rower.

For launch and landing, the rower was stowed in a middeck locker. For use, it attached to the seat studs on the Orbiter middeck floor. No seat was required for rowing in zero gravity; the crew member merely restrained his/her feet on the foot plates, grasped the handles, and rowed with a conventional motion.

The second generation rower, the MK-2 (Figure 8-20), was designed with features to compensate for the shortcomings of the MK-1. It flew for the first time on STS-64 in September, 1994. Among other modifications, the ability to quantify workload was incorporated into the new design.

MK-2 rower components included the rower ergometer unit, foot plates, and rowing handle. The rower ergometer unit consisted of two compartments: mechanical and chain drive. The mechanical compartment components generated and controlled workload, which was delivered to the subject through the rowing handle. The rowing handle was attached to a rope that ran from the subject through a pulley system and wound around a rope drum. One pulley was fitted with a load cell to measure force. The rope drum had an integral power spring to provide recoil torque and baseline workload. As with the MK-1 rower, a roller ramp clutch

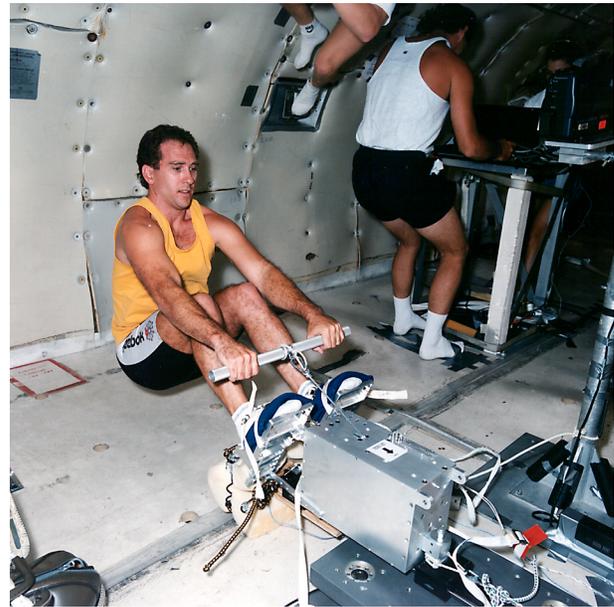


Figure 8-20. Subject Using MK-2 Rower on KC-135.

allowed the rope drum to deliver torque during each rowing stroke and to free-wheel during the recovery phase of each stroke. An optical encoder disc, attached to the rope drum, determined rope velocity and direction. The internal flywheel was used to provide inertial resistive load. A tension belt around the flywheel provided a variable load, controlled by embedded firmware. Tension in the flywheel belt was controlled by a servo motor/drive screw mechanism. Workload could be adjusted manually by use of a control knob extending outside the rower casing when powered operation was not possible. A position indicator gave the location of the traveler on the drive screw and was used as an indicator of the current workload setting.

In the chain drive compartment, a 1:3 rope drum-to-flywheel gear ratio increased the effective load from the flywheel and tension belt assembly. Chain drive was used to deliver torque from the rope drum to the flywheel. An idler pulley chain tightener assembly maintained proper chain tension and indicated the amount of chain wear. To ensure crew member safety, the chain drive compartment was completely sealed. Adjustable foot plates were padded and included straps to allow crew members to exercise without shoes. The plates, adjustable in inclination and foot length to accommodate all crew members, could be put on either end of the rower ergometer casing to allow flexibility in on-orbit operations. The rowing handle was fully padded for rowing and some resistive exercises. A quick release snap on the rope allowed the rowing handle to be easily interchanged.

The rower ergometer was designed so that it could be launched either in a locker or mounted to the floor in

place of a seat if fewer than seven astronauts were on a flight and the seat was not required. In this case, the rower ergometer attached to stud fittings in the vacant seat position.

CONCLUSION

As can be seen from the foregoing descriptions, EDOMP hardware ran the gamut from the simplest COTS items to complex, integrated systems employing state of the art technology. The development task involved mastery of a number of scientific and technical disciplines. As noted before, the hardware development schedules for all of the EDOMP equipment were extremely compressed; indeed, it could be said that the entire project was on the "fast track." While there were occasional malfunctions

and hardware failures, it is significant to note that the failure rates were no greater than in programs with much higher costs and longer development times.

In addition to the data collected and countermeasures developed, a major benefit of the EDOMP effort was the stable of hardware that is now available for use in ongoing research and operations. In addition to the EDOMP-derived hardware now used in an operational capacity on the Space Shuttle and Mir station, many items have become the basis for crew health care systems and human research equipment that will fly on the International Space Station, and perhaps on future flights to the Moon and Mars. This will be the ultimate legacy of EDOMP.

The success of EDOMP is a tribute to the ingenuity, dedication, and persistence of the engineers and technicians who designed, built, tested, and processed the hardware for flight.